Satellite and hydrographic observations of eddy-induced shelf-slope exchange in the northwestern Gulf of Alaska

S. R. Okkonen, T. J. Weingartner, S. L. Danielson, and D. L. Musgrave
Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, Alaska, USA

G. M. Schmidt
SAIC, SeaWiFS Project, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Received 12 February 2002; revised 20 October 2002; accepted 20 November 2002; published 13 February 2003.

[1] Satellite and hydrographic observations of oceanographic conditions in the northwestern Gulf of Alaska indicate that anticyclonic eddies propagating adjacent to the continental shelf alter the structure of the shelf break front and, in doing so, influence the shelf-slope exchange of biota and water mass properties. Eddies typically form in the northern Gulf of Alaska during fall and winter and propagate southwestward within an ~200 km wide corridor along and above the continental slope. Eddy activity within this corridor diminishes in the downstream direction. The trajectories of faster propagating (>4 km/day) eddies tend to lie closer to the shelf break than do the trajectories of slower propagating (~1.5 km/day) eddies. The interaction between azimuthal eddy currents and the shelf break frontal jet (1) establishes an upwelling zone, associated with the leading flank of the eddy, that strengthens cross-slope gradients, (2) weakens cross-slope gradients and promotes shelf-slope exchange where the eddy is adjacent to the shelf, and (3) reestablishes a weak upwelling zone associated with the trailing flank of the eddy. *INDEX TERMS:* 4520 Oceanography: Physical: Eddies and mesoscale processes; 4556 Oceanography: Physical: Sea level variations; 4536 Oceanography: Physical: Hydrography; 4528 Oceanography: Physical: Fronts and jets; *KEYWORDS:* eddies, shelf-slope exchange, hydrography, altimeter, Gulf of Alaska

Citation: Okkonen, S. R., T. J. Weingartner, S. L. Danielson, D. L. Musgrave, and G. M. Schmidt, Satellite and hydrographic observations of eddy-induced shelf-slope exchange in the northwestern Gulf of Alaska, *J. Geophys. Res.*, *108*(C2), 3033, doi:10.1029/2002JC001342, 2003.

1. Introduction

[2] The waters overlying the continental shelf and slope in the Gulf of Alaska are some of the most productive waters in the world ocean. They support large marine populations across all trophic levels and are home to extensive commercial and recreational fisheries. Paradoxically, for much of the year the shelf and slope are forced by downwelling-favorable winds [*Livingstone and Royer*, 1980]. Consequently, there is much interest in identifying the physical mechanisms that promote the tremendous production evident over shelf and slope.

[3] At other locations in the world ocean, eddies have been identified as agents that promote cross-slope exchange of water mass properties [e.g., *Churchill et al.*, 1986; *Pearce and Griffiths*, 1991; *Pingree and Le Cann*, 1992]. In the Gulf of Alaska, large-scale, cross-slope exchange has been attributed to estuarine-like circulation driven by the large seasonal freshwater input along the coastline [*Royer*, 1975]. More localized cross-slope exchange has been attributed to eddies near Kodiak Island by *Niebauer and Royer* [1981], *Musgrave et al.* [1992] and *Stabeno et al.* [2003] and along the Alaska panhandle/British Columbia coast by *Thomson and Gower* [1998] and *Crawford and Whitney* [1999]. Eddies along the eastern margin of the Gulf of Alaska tend to propagate westward away from the coast carrying coastal water properties into the interior of the Gulf of Alaska [*Tabata*, 1982; *Crawford and Whitney*, 1999] whereas eddies along the western margin tend to propagate southwestward along the coast [*Crawford et al.*, 2000; *Okkonen et al.*, 2001].

[4] Eddy-induced shelf-slope exchange in the Gulf of Alaska is illustrated by a SeaWiFS (Sea-viewing Wide Field-of-view Sensor) false-color image of near-surface chlorophyll pigment concentration acquired on 10 May 2000 during an extensive clearing of characteristically cloudy skies (Figure 1). A large anticyclonic (clockwise rotation) eddy centered southeast of Kodiak Island near ~55.6°N, 150.5°W (eddy A) is seen to be advecting phytoplankton from the waters over the outer shelf and continental slope into deeper water. Another large anticyclonic eddy centered at ~59°N, 144°W (eddy B) also appears to be advecting phytoplankton from the upper slope into deeper water. Two smaller, tongue-like features with elevated chlorophyll pigment concentrations near 56.8°N, 149°W and 57.8°N, 147.5°W lie between eddies A and B.

[5] Because cloudy conditions are the norm in the Gulf of Alaska, the SeaWiFS sensor, as well as other satellite-borne

0148-0227/03/2002JC001342$09.00

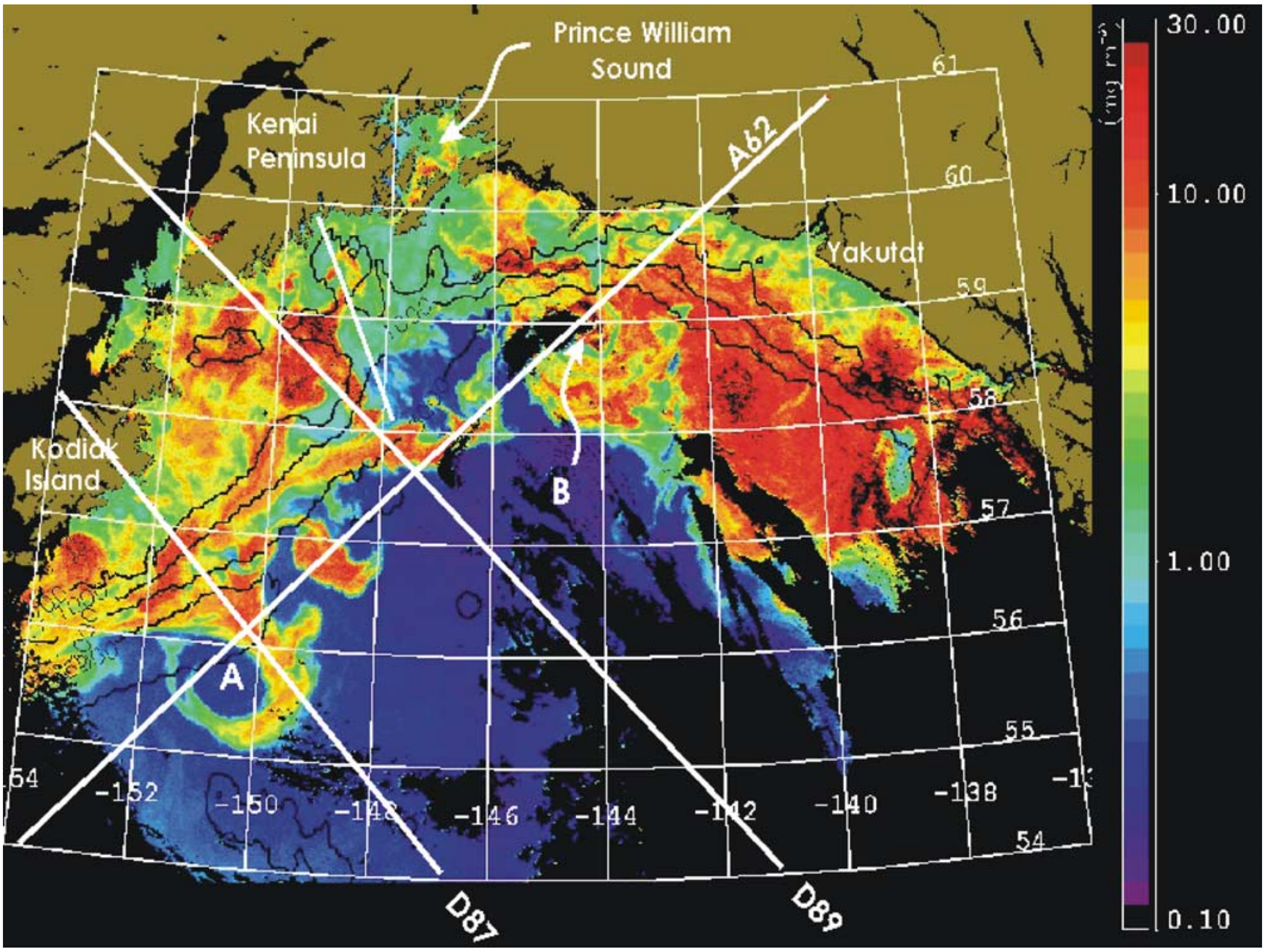

Figure 1. SeaWiFS false-color image of chlorophyll pigment concentration in the Gulf of Alaska on 10 May 2000. Cloud cover is black. TOPEX altimeter ground tracks A62, D87, and D89 are shown. The Seward hydrographic line runs from the Kenai Peninsula south-southeast to near the 3000-m isobath. The 200-m, 1000-m, 3000-m, and 5000-m isobaths are contoured in black.

visible and infrared wavelength sensors, can not reliably provide a regularly sampled, gulf-wide observational record with which to monitor the occurrence and evolution of Gulf of Alaska eddies and their influence on cross-slope exchange and phytoplankton distribution. Nonetheless, Figure 1 provides the context within which TOPEX altimeter measurements of sea surface height anomalies (SSHA) and hydrographic observations are interpreted herein to describe the seasonal and interannual variability of eddy-induced, shelf-slope exchange.

4. Summary and Discussion

[19] Comparisons of altimeter measurements of SSHA with hydrography acquired over the continental slope and outer shelf in the northwestern Gulf of Alaska show that anticyclonic eddies, propagating adjacent to the shelf, alter the structure of the shelf break front and influence the shelf-slope exchange of water mass properties. Considered within the context of eight and one-half years of altimeter observations of the Gulf of Alaska eddy field, these processes are seasonally modulated and interannually variable. Additionally, the size of a given eddy, the magnitude of its azimuthal currents, and its proximity to the shelf can be expected to influence its net effect on shelf break frontal structure and shelf-slope exchange.

[20] Upwelling zones that are established near the shelf break in association with the leading and trailing flanks of anticyclonic eddies locally strengthen the shelf break front. The shelf break front is weakened where eddy approach is closest to the shelf thereby promoting shelf-slope exchange. The principal limitations of the comparative analyses presented herein are the limited extent of hydrographic coverage seaward of the shelf break, the relatively coarse temporal hydrographic sampling period (1–2 months) relative to the TOPEX orbital repeat period (10 days), and the spatial separation (resulting in a phase lag) between the Seward Line and TOPEX ground track D89.

[21] An instance in which hydrography was acquired across the entire width of a large, ~200-km-diameter, anticyclonic eddy near Kodiak occurred in April 1988 [*Musgrave et al.*, 1992]. Relative to hydrographic conditions along the same section line when there was no eddy present, the eddy drew fresher, near-surface shelf water out over the continental slope, depressed the halocline ~50 m near the eddy center, and elevated the halocline ~40 m near the shelf break (their Figures 9e and 9f). The near-shore effect was to substantially weaken the shelf break front and the shelf break jet. Multiple drifter trajectories indicated an along-shore propagation speed of ~2 km d^{-1}.